Dr. Tim Grayson:
Tactical Technology Office (TTO)
Space Situational Awareness

What was that? Where is it going? What is it doing?

The greatest challenge to space situational awareness (or SSA) is the existence of totally unknown objects on orbit in space—natural objects like meteorites, debris from launch vehicles, or debris broken off from already orbiting assets. For safety and security, these objects must be detected, identified, and assessed without the benefit of any preconditional information as cues or guidance.

DARPA views space as having five aspects. One of these, space situational awareness, is the ability to track and understand what exactly is in orbit from either space or from the ground. Situational awareness is a key to ensuring the free use of space and an enabler of other space operations. By providing real-time location and status of friendly spacecraft, it is a tool to monitor these operations and conduct them more efficiently. At the same time, it helps protect these assets and operations by providing warnings of potential hazards—natural or manmade, intentional or unintentional—in a manner timely enough to allow preventive actions to be taken.

Fundamentally, SSA involves both the generation and management of information to provide current and accurate answers to the questions asked at the beginning of my talk. In many cases, this is a fairly straightforward proposition. For satellites under our control or under the control of other entities that choose to work cooperatively, much of this information is provided by telemetry and self-reporting.

Even for these cooperative space assets, however, it is prudent to confirm these reports with noncooperative sensor data to allow for malfunctions or erroneous reporting. As space operations become more complex, such as the autonomous servicing described in the Orbital Express briefing, it is beneficial to have third-party monitoring capability to alert to any mishaps.

Of much greater concern is the problem of noncooperative SSA; in other words, answering these questions when telemetry or even fundamental cueing and identification of an on-orbit object is not available, the enigma event.

Existing SSA capabilities focus on surveillance and assume a fair degree of preexisting information. A catalog of all known objects in orbit, which is maintained by the U.S. Space Command, is updated on a recurring basis, depending on the object's orbit and characteristics. While this system has functioned very well to date, it faces many challenges as the space environment becomes increasingly more complex. Perhaps the greatest is the overload of operators and the time in which catalog entries can be updated.

As the number of objects in orbit grows exponentially, the workload on these operators will potentially become overwhelming and result in less frequent observations and catalog updates.

This problem is exacerbated by the desire to monitor small objects. Constantly increasing quantities of debris generated by our space activities threaten the safety of manned space operations as well as the functioning of nationally important, high-value satellites. Furthermore, spacecraft design capability is allowing very small microsatellites, also described during the Orbital Express briefing, that are hard to observe and can be deployed in great numbers.

As we push to develop sensing capacity to observe these ever-smaller objects, the jobs of the catalog monitors will be further complicated. Many detections of this class of objects will lack the benefit of launch cues or prior identification, adding substantially to the challenge.

DARPA is developing concepts for new technologies to address many of these challenges. An early focus will be development of new sensor technologies to provide more timely detection and characterization of smaller objects. Any given sensor capability might be developed as a stand-alone technology program, but a constant system focus is being maintained to ensure that individual technologies complement each other. Finally, information management tools will be developed in parallel with hardware technologies to ensure that operators can handle the increasing load of sensor data made available by these new sensors.

The focus of DARPA's SSA sensor development efforts will be on objects in deep space, primarily in geosynchronous (or GEO) orbits, although some of the technologies under consideration also have relevance to objects at low-earth orbits (or LEO). The existing space surveillance network has good sensing capability against LEO objects. Wide-area search and detect is best accomplished using ground-based radar sensors because of their ability to cover a large field of view with a single beam. For characterization of LEO objects, both optical and radar techniques have utility.

At GEO—or, for that matter, everything higher than a high LEO—the situation reverses. Radar signals can no longer make the very long roundtrip distances without narrow beams and long-dwell integration, both limiting uncued search capability. At the same time, high-earth objects are almost always illuminated by the sun, making them observable from ground-based optical systems as long as the telescope is in the dark.

The existing GEO search capability is provided by the Ground-Based Electro-Optical Deep Space Surveillance (or GEODSS) System. The new DARPA Space Surveillance Telescope (or SST) Program seeks to provide improved capability over the existing GEODSS System by extending performance to a more rapid uncued search against smaller objects. Obtaining sufficient resolution for identification and characterization is extremely challenging at GEO with an optical system.

Instead, the DARPA Deep View Program seeks to develop a radar-based space object identification capability by both addressing the daunting transmitter requirements and developing signal processing necessary for a robust GEO characterization capability.

Rounding off ground-based GEO sensing capability will be space-based augmentation. As already noted, Orbital Express will include its own organic monitoring capability of a satellite's surroundings. This capability can be extended to monitor the vicinity of a satellite for potential hazards that go undetected by a ground-based network of sensors.

As described in the previous table, SST is the key element of deep space search and track. It employs some novel breakthrough technologies to go the next step beyond GEODSS performance. Like GEODSS, SST is envisioned as a ground-based, optical, nonimaging telescope. Rather than seeking high-resolution, as is commonly the goal of most telescope systems, both GEODSS and SST seek to cover as much area as possible by using a wide field-of-view telescope design. At the same time, large apertures serve as "light buckets" that facilitate detection of small objects. Combined wide field of view and large aperture are frustrated, however, by the wavefront curvature that results from what is known as a very "fast" telescope. In other words, the wavefront of the incoming light is curved to an extent that it cannot be imaged onto a conventional flat focal plane array in focus across the entire array.

Early search telescopes using film as their “sensor" literally curved the surface of the film to match the wavefront curvature. These systems, however, are very inefficient both optically and operationally because of the limitations of working with film. Existing systems use electronic focal plane sensors and attempt to work around the aberration limitation by using very complex "compensators" that attempt to flatten the wavefront. Unfortunately, these compensators are very complicated and expensive and are limited in their ultimate ability to scale to very large telescopes. As a result, existing systems are still relatively limited in both their detection sensitivity and field of view. The field-of-view limitations prohibit existing systems from conducting true synoptic searches and, instead, are limited to cued updates of catalog objects to confirm their current position and metrics.

The SST approach borrows the best of both legacy approaches using novel focal plane technology. As will be described, it is possible to curve highly thinned focal plane array material and still maintain electrical integrity. As a result, it is feasible to construct a telescope with both very large aperture and field of view.

Instead of using a compensator, the wavefront curvature is designed into the telescope, and the focal plane array is curved to match the wavefront of the incoming light. The result is an almost unlimited ability to scale both aperture size and field of view to provide an uncued synoptic search capability of small objects at GEO.

To further enhance search performance, the SST Program is aggressively pursuing a lightweight system design to minimize step-and-settle times. A key requirement for achieving that goal is the use of lightweight optics. An ongoing optics study is examining options for the use of next-generation optical fabrication techniques, such as thinned glass, silicon carbide, and nanolaminates. In addition to improved SST capability, this work will help advance the general optics fabrication state of the art.

This figure illustrates the degree of aberration encountered in a system like the SST and the importance of a continuously curved focal plane array. For a notional telescope design that captures the desired system attributes of the SST, the depth of focus is only about 10 microns. One could attempt to tile up a piecewise-curved focal plane using many discrete array tiles, each canted to form a curved surface.

Unfortunately, in addition to the practical alignment and wiring challenges of this approach, it still does not provide the necessary degree of curvature. For discrete tiles of only a few centimeters on a side, the wavefront still varies by close to 200 microns across a tile (as shown in the figure) over an order of magnitude greater than the depth of focus. The result is a smearing of the light energy from a point source over multiple pixels, as shown on the right, severely limiting overall detection capability.

The SST approach uses curved focal plane technology originally developed by the DARPA Microsystems Technology Office (MTO). The original inspiration for this concept was the realization that focal planes that had been thinned sufficiently for back illumination were flexible and could easily be bent to an unlimited variety of shapes. Under the MTO program, MIT's Lincoln Laboratory and Raytheon Corporation developed the controlled fabrication process to maintain electro-optical characteristics, namely dark current and circuitry fabrication topology for curved focal planes. To date, they have developed proof-of-concept prototypes that demonstrate compliance with both mechanical and electro-optical requirements.

For the SST design, multiple tiles would be individually shaped to a constant radius of curvature and then tiled to form a larger array. In addition to ensuring both the physical and electro-optical tolerances are met for each tile, there will be significant engineering challenges for the overall dewar and sensor design. The mounting plate of the dewar will need to meet curvature tolerances that are maintained at low temperatures.

Moving on to the Deep View object characterization concept as described in the sensor overview, this capability would be provided at GEO using a ground-based radar characterization system. The keys to GEO operations are transmitter power and aperture size to accommodate range and bandwidth to provide resolution. The key technologies will be described on the next chart.

The fundamental system concept is to develop high-resolution SAR object images when there is some object motion or a high-resolution range profile of the object when it is truly geostationary. Automated and semi-automated tools will process the signatures to extract useful information about the object.

For many objects, such as cataloged satellites, this characterization involves evaluating status. For example, a satellite might be exhibiting less than optimal power levels, and characterization could indicate improper deployment of a solar panel. In other cases, the characterization technique might be used to classify an object as one of several possible known objects. The simplest example is the classification of an object as either natural, manmade debris, or an active satellite. Characterization could also involve establishing specific track identification when multiple small payloads are released from the same boost vehicle.

The end result of this processed signature data is a more complete, precise picture of the state of on-orbit space objects.

The key to achieving both high transmit power and bandwidth is in the transmitter tube design. To obtain bandwidths necessary to provide the level of resolution desired for Deep View capability, it is necessary to start from a very high center frequency. The current concept is to operate at the edge of the atmosphere's transmission at W-band.

Deep View transmitter requirements will push W-band tube performance beyond its current state of the art. Attempts will be made to obtain as much bandwidth and power from a single tube as possible. Multiple tubes will then be combined to reach the final system bandwidth and power goals. An initial transmitter design study now underway will determine the best combination of tube- and power-combining technologies to reach the ultimate system goals.

In summary, DARPA is in the process of initiating programs to demonstrate novel multiple capabilities for the next-generation SSA system.

The SST Program is conducting both system and optical fabrication studies to determine the final telescope design requirements and approach. Fabrication of both focal plane tiles and optics will commence next year with a goal of telescope completion and demonstration in fiscal year 2008.

The Deep View Program is pursuing a transmitter design study that will determine the best approach to transmitter tube and beam-combining technology. Beginning next year, detailed designs for the transmitter and receiver will be undertaken with an ultimate integration into the existing SSA programs. Demonstration of a completed capability is also expected in FY 2008.

Parallel to these sensor hardware programs will be the development of signal processing algorithms to extract the most available information of Deep View signature data and automate the overall SSA information management process. Future opportunities will exist for involvement in some aspects of sensor component design as well as development of processing algorithms. When combined with the inherent space-based capability of Orbital Express, a next-generation SSA system of unprecedented capability could provide real-time knowledge of what is really happening in orbit around our planet.